

FIRE AND INVASIVE SPECIES WITHIN THE TEMPERATE AND BOREAL CONIFEROUS FORESTS OF WESTERN NORTH AMERICA

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ABSTRACT

Invasive, nonnative plant species have been a concern of land managers within the temperate and boreal coniferous forest eco-region for nearly a century. Fire management, timber harvest, grazing, mining, recreation, and agriculture have not only exacerbated invasive species establishment and spread, but have been impacted by such species as well. Some invasive species, such as cheatgrass, have increased fire frequency while others, such as diffuse knapweed, have the potential to decrease fire frequency. Such changes in disturbance regimes have altered land use patterns. Fire exclusion in dry forest ecosystems has led to large catastrophic wildfires, increasing the potential for invasion by nonnatives and further altering ecosystems. Clear-cut harvesting and prescribed burning of residual fuels in coastal coniferous forests promotes the establishment and spread of invasive species to the detriment of native species. Fire and land management planners should consider practices that minimize invasion of nonnatives. Similarly, managers should consider the potential benefits of prescribed fire on increased resistance of native plant communities to invasion or as a method of invasive species control. Monitoring current fire management activities and the initiation of fire effects research will be important to better address invasive species during ecosystem restoration activities within this eco-region.

keywords: boreal forests, fire, fire management, temperate forests, weeds.

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INTRODUCTION

Fire is an important disturbance process in most ecosystems. Ecosystem, community, and population structure are modified by fire, which favors certain species or creates conditions for new species to invade (Agee 1993). Fire usually favors early successional species and communities, but it may also maintain or accelerate community structure and composition. Unfortunately, many native early seral species have been replaced or are out-competed by nonnative invasive species (i.e., weeds), which can alter successional pathways and subsequent fires (Harty 1986, Vitousek 1986, Hobbs and Huenneke 1992, Harrod 1994). The interaction of fire and other disturbance factors, such as logging, grazing, and road building, have allowed nonnative species to invade or colonize native forest ecosystems (Vitousek et al. 1996). This paper focuses on invasive species (hereafter, invasives) and fire in the temperate and boreal coniferous forest eco-region.

Classification schemes for forest biomes are ambiguous, so we will consider the temperate and boreal coniferous forest eco-region as the mountainous areas of the western United States and Canada, and the taiga (McNab and Avers 1994, Agee 1999). Fire is obviously important in all forest types within this broad geographical area, but the degree to which invasives

influence or are influenced by these forests varies. Therefore, we focus our attention on those forests where information is available.

Invasive species have emerged as one of the most critical threats to the protection of biodiversity (Wilcove et al. 1998). The impacts on native species range from competition for resources (e.g., Melgoza et al. 1990, Hester and Hobbs 1992, Mesléard et al. 1993, Huenneke and Thomson 1994), hybridization (Thompson 1991), nitrogen fixation introduced or increased in natural areas (Vitousek et al. 1987), changed hydrologic cycles (Carman and Brotherson 1982), increased sedimentation (Blackburn et al. 1982), and increased disturbance cycles (Bock and Bock 1992, D'Antonio and Vitousek 1992). A recent estimate put the economic cost of invasive plants in natural areas, agriculture, and gardens at US\$34 billion per year (Pimentel et al. 2000).

Most invasive species are extremely efficient at exploiting the initial decrease in competition that follows a disturbance such as fire, especially one that is hotter than normal due to an increase in fuel load (Hobbs and Huenneke 1992). The reduction in species diversity following the disturbance allows invaders, often inefficient in resource use, to establish vigorous populations that ultimately exclude recolonization of native species (Pimm 1984, Drake 1990).

Fire in temperate and boreal coniferous forest ecosystems influences invasive species, but these systems are also influenced by invasives. Many invasive species, such as spotted knapweed (*Centaurea maculosa*) and leafy spurge (*Euphorbia esula*), are fire tolerant (USDA Forest Service 2000). Fire may cause existing plants to be killed or resprout, stimulate seeds to germinate, create suitable sites for establishment, or eliminate competition for rapid spread of existing plants. On the other hand, the presence of invasives may increase or decrease fire frequency and intensity. These relationships are not mutually exclusive and are often related.

We synthesize the state of knowledge of the interaction of fire and invasive plants in the temperate and boreal coniferous forest eco-region. We will discuss land use and management effects on invasive species and fire, the influence of fire on selected invasive species, the influence of selected invasives on fire, fire management practices and invasives, and research needs.

LAND USE AND MANAGEMENT EFFECTS ON INVASIVES AND FIRE

The types of land use and management within the eco-region are highly diverse. Timber production, livestock grazing, agriculture, wildlife management, and recreation are the most prominent land uses that have been occurring for more than a century (Quigley et al. 1996, Sierra Nevada Ecosystem Project 1996). Invasive plant species have often interfered with land management objectives, and their spread or establishment has been exacerbated by these and other land management activities. Some invasive plants were introduced accidentally, but most were introduced intentionally for wildlife habitat improvement, ornamental purposes, soil conservation, crop or other uses, and then escaped into native plant communities (Reichard 1997). Many present-day land uses and management activities, such as fire, continue to influence invasive plants. The number of species present, the continued spread of invasives throughout the eco-region, and the potential for new introductions are of great concern for many land managers.

Fire management within the eco-region is an important aspect of invasive species management. Fire and other disturbances usually facilitate invasion by nonnative species (Hobbs and Huenneke 1992, Vitousek et al. 1996). However, prescribed burning and other forest restoration activities can help prevent the establishment of invasive species. Covington et al. (1997) have suggested that thinning and burning in dry forest ecosystems should increase the diversity and productivity of native plant communities, which should be more resistant to invasion by nonnatives (Elton 1958, MacArthur 1970, Crawley 1986, Case 1990, Law and Morton 1996, Tilman 1997, Levine and D'Antonio 1999; but see Huston 1997 and Higgins et al. 1999).

High severity wildfire creates suitable habitat for

many invasive species and invasives may become established if a seed source is available. Many dry temperate forests within the eco-region have become susceptible to catastrophic wildfires because of the dense forest structure that resulted from a century of fire exclusion and past management practices (Habeck 1976, Kilgore and Taylor 1979, Agee 1994, Hessburg et al. 1994, Jensen and Everett 1994, Johnson 1994, Quigley and Arbelbide 1997). High fire severity in boreal and mesic temperate forests is common (Agee 1999). Once established post-fire, invasive species may prevent the establishment or out-compete native species by strongly exploiting available resources (Vitousek 1986), by reducing native species fitness through allelopathy (Muir and Majak 1983), or other interactions, such as decreasing important mycorrhizal fungi (Goodwin 1992). The impact of such invasions is decreased biodiversity, particularly species diversity (Soulé 1990, Harrod et al. 1996, Randall 1996, Higgins et al. 1999). Current forest management aims to create sustainable ecosystems, maintain biodiversity, and develop or maintain healthy plant communities that are relatively resistant to invasives (Harrod 1994, Quigley et al. 1996, Sheley et al. 1996, USDA Forest Service 1996, Agee 1998, Cortner et al. 1999).

Influence of Fire on Invasives

The response of invasive plant species to fire has not been extensively studied. We summarize the literature on a few species common in temperate and boreal forests, but much more fire effects information is summarized in the Fire Effects Information System on-line database (USDA Forest Service 2000).

In general, plants have evolved a variety of life histories that allow them to survive in a frequent-fire environment. Rowe (1981) has classified these as: (1) invaders—dispersive, pioneering species requiring disturbance to occupy a site; (2) evaders—species with relatively long-lived propagules stored in the soil or on the plant; (3) endurers—resprouting species; and (4) resisters—species that can survive low intensity fire due to morphological characteristics, such as thick bark. Avoider species have no special adaptations to fire (Agee 1993). In addition, plants can be classified as fire increasers, fire maintainers, or fire decreasers, based on changes in frequency following fire (Tveten and Fonda 1999). Invasive species in temperate and boreal forests have a number of life history characteristics that allow them to employ one or a combination of the above strategies, but most are either invaders, evaders, or endurers. Understanding life history strategies of invasive species will help land managers evaluate the appropriate use of fire as a control measure or the potential positive effects on invasives when fire is used for other management purposes.

Invaders have efficient seed dispersal and routinely establish satellite populations in nearby disturbed sites. These species also tend to be fire increasers, although they may or may not maintain their importance for an extended period after fire. For example, Halpern (1989) found that wood groundsel (*Senecio sylvati-*

cus), a European winter annual, dramatically increased in cover and frequency 2 years following slash burning, but then rapidly declined in importance in Douglas-fir (*Pseudotsuga menziesii*) forests in the western Cascade Range of Oregon. Yellow starthistle (*Centaurea solstitialis*) is a winter annual, native to dry open habitats in southern Europe, which has spread rapidly into open forests and rangelands in the western United States (Roché et al. 1994, DiTomaso et al. 1999). This species spreads rapidly following establishment within burned areas (C.G. Johnson, Jr., USDA Forest Service, personal communication), but 3 consecutive summers of prescribed burning can reduce starthistle seedbank and seedling density by 99% and vegetative cover by 91% (DiTomaso et al. 1999). Yellow salisfy (*Tragopogon dubius*), another European annual, can quickly invade disturbed sites, and it was found to increase slightly in both cover and frequency following fall wildfire as compared with a non-burned site in the Selway-Bitterroot Wilderness, Idaho (Merrill et al. 1980). In the eastern Cascade range of Washington, Scherer et al. (2000) found that bull thistle (*Cirsium vulgare*) invaded post-harvest, spring and fall burn treatments, and thistle cover was about 2 times that of residual native species. In boreal forests of central Saskatchewan, the European invasive field sow-thistle (*Sonchus arvensis*) was not present in undisturbed forests, but invaded burned sites (Peltzer et al. 2000).

Evaders are generally eliminated by fire, but evade elimination from the site through germination from a well-developed seed bank. Leafy spurge is a nonnative species found throughout much of the western United States and Canada in open ponderosa pine (*Pinus ponderosa*) and grasslands (USDA Forest Service 2000), areas characterized by frequent fire. Most of the fire-effects research has been conducted in the Great Plains, but should apply to forests where this species occurs. For example, Cole (1991) and Fellows and Newton (1999) found that leafy spurge increased in stem density the first year following both spring and fall burns. Although this species is rhizomatous (Taylor 1990), the increase was presumably due to the large seedbank, seeds of which can remain viable up to 8 years (Selleck et al. 1962). However, Dix (1960) reported a decrease in frequency of leafy spurge from 17% to 0% following a fall burn. Diffuse knapweed (*Centaurea diffusa*) has become established on many open forest sites in the western states and British Columbia (Powell et al. 1997) and shows a similar response to burning as leafy spurge. This biennial species is killed by fire (R.J. Harrod, personal observation), but recolonizes sites from a well-developed seed bank, the result of prolific annual seed production of about 26,328 seeds/m² (Roché et al. 1986, Harrod and Taylor 1995). However, Watson and Renney (1974) note that burning could be an effective control measure with vigorous grass regrowth while Strang et al. (1979) note that knapweeds rarely invade burned areas. St. John's-wort (*Hypericum perforatum*) is an aggressive perennial invasive that reproduces largely by seed (Taylor 1990). Briese (1996) reported that fire promoted development of St. John's-wort populations

presumably from a well-developed seed bank. Finally, Tveten and Fonda (1999) found fall burning killed most Scot's broom (*Cytisus scoparius*) plants, but that post-fire germination of the seedbank could repopulate oak woodlands and prairies in western Washington. A follow-up burn in 1 to 2 years could be an effective strategy to control evaders.

Endurer species resprout from the root crown or rhizomes and many invasive species employ this strategy. Dalmatian toadflax (*Linaria dalmatica*) is an introduced species from the Mediterranean now widespread throughout the western United States and Canada (Roboker 1974). It is highly rhizomatous and resprouts vigorously following hand-pulling or clipping (Harrod 1989), and it is assumed to have a similar response to fire as either a fire maintainer or increaser. Canada thistle (*Cirsium arvense*) is a strongly rhizomatous nonnative species capable of out-competing native grasses and forbs in open forests, overgrazed areas, and along roadsides. Early spring fire top-kills Canada thistle and plants resume growth or even increase sprouting from perennating buds on rhizomes (Evans 1984, Hutchison 1992). Hutchison (1992) suggests the most effective way to control this species is with 3 consecutive years of late spring burns between May and June. However, Scherer et al. (2000) found that Canada thistle invaded both spring and fall burn sites in eastern Washington. Undoubtedly, this species established from numerous wind-borne seeds, which can remain viable for up to 20 years (Hutchison 1992). The combination of high seed output, long seed viability, and its rhizomatous nature suggest the judicious use of fire to control Canada thistle. Although a native species, blue-joint grass (*Calamagrostis canadensis*) is a perennial rhizomatous grass found in boreal forests. It is often considered a problematic invasive in white spruce (*Picea glauca*) plantations (Lieffers et al. 1993). Low-intensity fire may increase the potential for resprouting (Dyrness and Norum 1983), but blue-joint grass may be out-competed by other native forbs that become established post-burn (Lieffers et al. 1993). Fires that remove large amounts of rhizome, consuming 20–30 cm of the litter layer, will greatly reduce the subsequent spread of this grass (Lieffers et al. 1993). A Eurasian species, Russian knapweed (*Centaurea repens* [= *Acroptilon repens*]) is an aggressive rhizomatous perennial found throughout the western United States and Canada (Watson 1980, Taylor 1990). This species is stimulated by mowing (Watson 1980) and presumably resprouts after being top-killed by fire (USDA Forest Service 2000). Black locust (*Robinia pseudoacacia*) is a shrub native to the eastern United States, but was introduced into forest areas in the western United States primarily for slope stabilization. This species readily resprouts following cutting or burning (R. Harrod, personal observation). Other invasive shrub species, such as Russian olive (*Elaeagnus angustifolia*) and gorse (*Ulex europaeus*), are likely to resprout following fire.

Influence of Invasives on Fire

Invasive species are not only affected by fire, but some species can influence fire and fire regimes. Co-

nifers, native shrubs, and grasses influence fire regimes in temperate and boreal forests. However, some invasives have already changed or have to potential to alter fire regimes. The most well-known example is cheatgrass (*Bromus tectorum*)—perhaps no other species has had such a dramatic effect on western United States ecosystems. Cheatgrass was introduced to western North America sometime ca. 1890 (Mack 1981), and it became widespread over the early part of the 20th century throughout the western United States and Canada. This species is highly competitive and able to replace native species for indefinite periods (Daubenmire 1975). In open pine forests and adjacent non-forest vegetation types, cheatgrass has decreased the fire-free interval so that fires occur frequently, in some cases every 5 years or less (Billings 1994, Peters and Bunting 1994). Fires have not only become more frequent in these areas, but their intensity and extent have increased (Peters and Bunting 1994). Many forests throughout the West have become dense and susceptible to large, catastrophic wildfires (Agee 1993, 1998). The presence of cheatgrass-dominated ecosystems adjacent to these dense forests is likely to cause more frequent and intense wildfires.

Lehmann lovegrass (*Eragrostis lehmanniana*) is an imported species from South Africa into Arizona. It is primarily found in semi-desert grasslands, but Anable et al. (1992) note the species use by state and federal agencies for erosion control even on forest landscapes. Like cheatgrass, Lehmann lovegrass increases fire frequency (Anable et al. 1992); managers may want to carefully consider seeding this species, particularly in high-density forests with high fuel loads that have resulted from fire exclusion.

Some invasives may have the potential to decrease fire frequency. Diffuse knapweed is reported to have allelopathic compounds that can inhibit the growth of other plants (Watson and Renney 1974, Strang et al. 1979, Muir and Majak 1983). Diffuse knapweed dominates sites—often to the exclusion of other herbaceous species—and the community becomes sparsely vegetated. It is conceivable, although not studied, that diffuse knapweed could reduce fire frequency and intensity by the lack of continuous fuel development. Such changes in fire regimes due to this species warrant further investigation.

FIRE MANAGEMENT PRACTICES AND INVASIVES

Firefighting has been occurring for almost a century in western forests (Pyne et al. 1996). The process is simple: starve the fire of fuel by creating firelines where fuels are removed to expose mineral soil. Firelines are created by hand tools and equipment, so that the size and extent of firelines varies with the circumstance. In addition, roads, safety zones, aircraft landing zones, fire camps, and staging areas may be constructed during large fires. To a lesser extent, prescribed fires also necessitate firelines and other disturbed areas. All of these firefighting and prescribed fire activities pro-

vide suitable habitat for invasive species, which can become established in these disturbed areas before native vegetation can re-invade.

Land managers have traditionally suppressed wildfires because they considered them damaging. People have also traditionally tried to recover burned areas to some pre-fire condition (Pyne et al. 1996). Managers often rehabilitate post-fire suppression damages. Recovery and rehabilitation activities have included post-fire seeding (mostly with nonnative species) in order to prevent erosion and to revegetate burned areas. These nonnatives have the potential to further invade adjacent areas. Occasionally, aggressive nonnative species can be present in seed mixtures and accidentally become established over broad areas.

The most important aspect of invasive species management is prevention (Harrod 1994). Fire management should be conducted in ways that prevent establishment of invasive species so that damage to ecosystems does not occur and expensive control measures are not needed. The use of heavy equipment, the location of firelines, the placement of landings, and other suppression activities should be thoughtfully considered regarding potential resource damage. Minimum suppression techniques should be considered in wilderness or other sensitive areas. To the extent possible, native grass sod and other native species should be replaced in firelines. Native seed should be considered over nonnative seed when possible. Furthermore, seeding in burned areas should be carefully considered because post-fire seeding may have negative impacts on native vegetation. For example, Schoennagel and Waller (1999) found that post-fire seeding with a mix of nonnative grasses and a legume significantly reduced the cover of native species and reduced the abundance of conifer seedlings.

RESEARCH AND MONITORING NEEDS

Land managers must understand fire effects on invasive plant species in order to implement fire management programs that are consistent with ecosystem management objectives for temperate and boreal forests. Furthermore, managers must monitor and evaluate prescribed fire activities to direct ecosystem management toward achieving desired outcomes (Ringold et al. 1996, Tolle et al. 1999). Fire effects are still poorly understood for many species, and potential changes in disturbance regimes in temperate and boreal forests by invasives are almost unknown. There are many species and many ecosystems to study, so we recommend the following approach regardless of the species or system.

Monitoring is the measurement over time that indicates movement toward or away from an objective (Tolle et al. 1999), while *research* refers to a study designed to determine the cause(s) of some observed ecological phenomenon. Monitoring data are usually of limited value in determining causes of change, but can be more costly than rigorous research. Monitoring and research methods are numerous, so it is important

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that a fire-effects research-and-monitoring strategy consists of the following characteristics (Ringold et al. 1996, Tolle et al. 1999):

- (1) A clearly defined question(s) to be addressed. In other words, determine what is the purpose of the research or monitoring. Consider temporal and spatial scales, variables to be sampled, and statistical design.
- (2) Ecological and political importance. Some data are limited in scope and may not be important ecologically or managerially. Carefully consider the scope of information to be collected.
- (3) Linked to specific ecosystem management objectives. For example, will the research assist managers in restoring or maintaining sustainable forest ecosystems?
- (4) Simplicity and adaptability. Many different researchers may collect data from long-term research projects, so simple and adaptable sampling methods are critical. In addition, research funds can be limited, so a simple design may be more economically feasible than a complicated one.
- (5) Technical transfer. Research and monitoring results are not useful unless the findings are presented in the appropriate outlets. Technical reports, journal articles, proceedings papers, and internet sites are examples of outlets for managers.
- (6) Credibility. Peer review should be an integral part of the initial and final stages of research and monitoring projects.

Fire effects on invasive plant species can be studied at the species level or at the landscape level. We recommend a demographic approach for understanding interaction with fire at the species level. The effects of fire on life-history traits, such as seed germination or plant growth and development, are interesting and may help us to understand causal mechanisms, but such studies alone do not answer perhaps the most important question: do invasive species populations increase, decrease, or remain stable following fire? Demographic methods used are beyond the scope of this review, but the reader should refer to classical works by Harper (1977) and Caswell and Werner (1978), and more recent papers by Silvertown and Lovett Doust (1993) or Grant and Benton (2000). The effects of timing of burn on individual species is an important area of research.

At the landscape level, more research is needed to understand the effects of invasives on fire regimes. Widespread invasions of knapweed species, for example, undoubtedly influence fire frequency and intensity. It might be useful to develop models that predict fire behavior and fire effects with widespread invasions. Research and monitoring could be focused on boreal forest ecosystems because of the lack of information regarding invasives and these systems.

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